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PALEOEROSION SURFACES AND KARST MANIFESTATIONS INCLUDING "EGYPTIAN ALABASTER" IN GABAL HOMRET SCHAIBUN-GABAL SANNUR AREA, EAST OF THE NILE VALLEY, EGYPT

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The carbonate landforms and related weathering products of this area are the result of paleokarstification processes through three subsequent erosion cycles that started after the Eocene uplift and continued up to Pliocene time. Deep weathering processes led to the continuous lowering of the landscape and the creation of three paleoerosion surfaces of different altitudes and morphologic character. These are delineated by karst profiles with typical karst features and karst deposits. Paleotopography, paleoclimate, lithology, structure, karst environments (surface and subsurface) and diagenesis are the fundamental factors that controlled the distribution, formation, composition and textures of the karst products of each surface, together with the genetically related "Egyptian Alabaster".

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INTRODUCTION

This work deals with the morphologic evolution of the carbonate outcrops of G.Homret Schaibun - G. Sannur area, in the aim of clarifying the mode of formation of the associated commercial rocks. The area represents the down stream part of a very large basin extending from the western side of the Northern and Southern Galala plateaux to the Nile Valley, east of Beni Suef and Minia Governorates (Fig. 1). The carbonate rocks of this area are quarried for

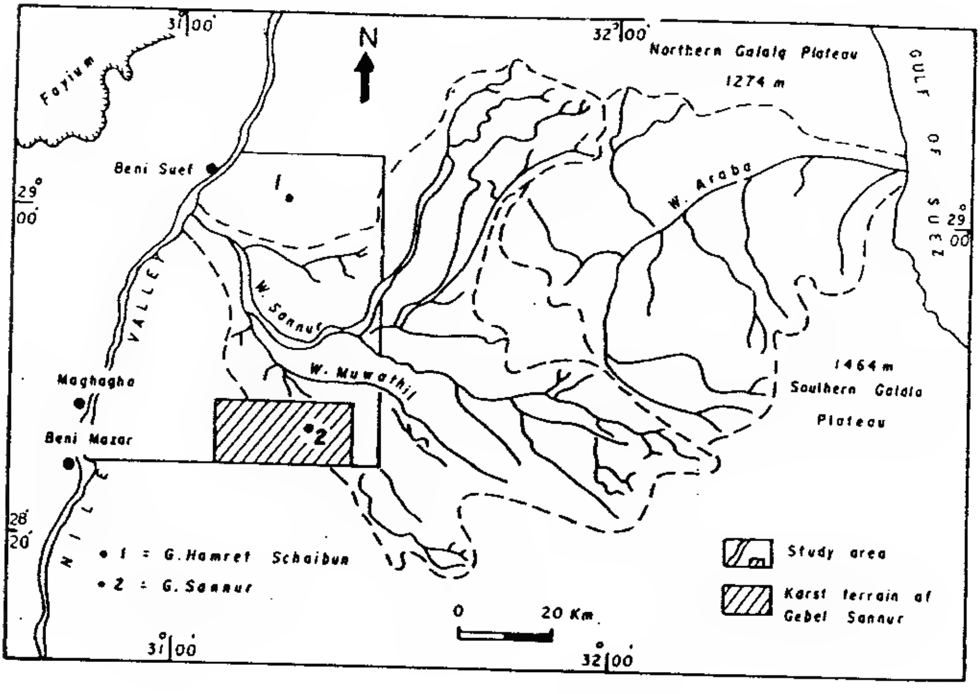


Fig. 1.Location map.

building and decoration purposes which include the commercially known "Egyptian Alabaster and Bucchino" at W. Sannur and "Travertine" at G. Homret Schaibun. To describe the main physiographic units of this area, a general geomorphic-orographic map and representative topographic profiles were constrcuted. These are based on topographic sheets (scale 1:100,000) and aerial photographs (scale 1:40,000). The morphologic features were confirmed in the field and representative localities were selected for detailed investigations. Special attention is paid to G. Sannur area since it represents a spectacular karst terrain, with a deep and well preserved karst profile that includes the main quarries of the "Egyptian Alabaster". The karst features and sediments of this terrain are described and discussed in detail. Qualitative and quantitative drainge analyses were also carried out to give the full picture about the drainage basin evolution throughout the denudational history of the area. The stratigraphy and lithology of the country rocks are deduced from the study of six representative columnar sections.

The term "Oriental or Egyptian Alabaster" was first introduced by Legrain (cited in Fourtau, 1904) for the crystalline calcium carbonates of the Nile Valley. Fourtau *(op. cit.)* was also in favour of this term to distinguish the rocks in question from the proper alabaster (massive or compact variety of gypsum delicately shaded or tinted with light coloured tones (Gary *et al.*, 1977). These rocks were also described as stalactites and stalagmites (Newbold, 1848 and Dana, 1932); recrystallized calcium carbonates (Farag and Ismail, 1959 and Said 1962) or marble (El Hinnawi and Loukina, 1971 and 1972). The composition, textures and origin of the "Egyptian Alabaster" were discussed by Akaad and Naggar (1963, 1964 a,b and 1965), El Hinnawi and Loukina *(op.cit.)*, and Kamel *et al.* (1990). Most of these authors related the formation of the "Egyptian Alabaster" to the action of underground carbonated and (or) thermal water along faults and fractures with recrystallization, also as fracture and cave fillings. None of the proposed models could fully explain the origin and the evolution of these carbonate rocks and their relation with the denudational history of the country rocks and the formation of the associated soil materials and products.

GEOLOGIC SETTING

The exposed rocks of the study area are mainly Middle and Upper Eocene limestones with shale interbeds. Four rock units could be distinguished (Fig. 2), namely, from base to top: Qarara, El Fashn, Schaibun and Maadi forma-

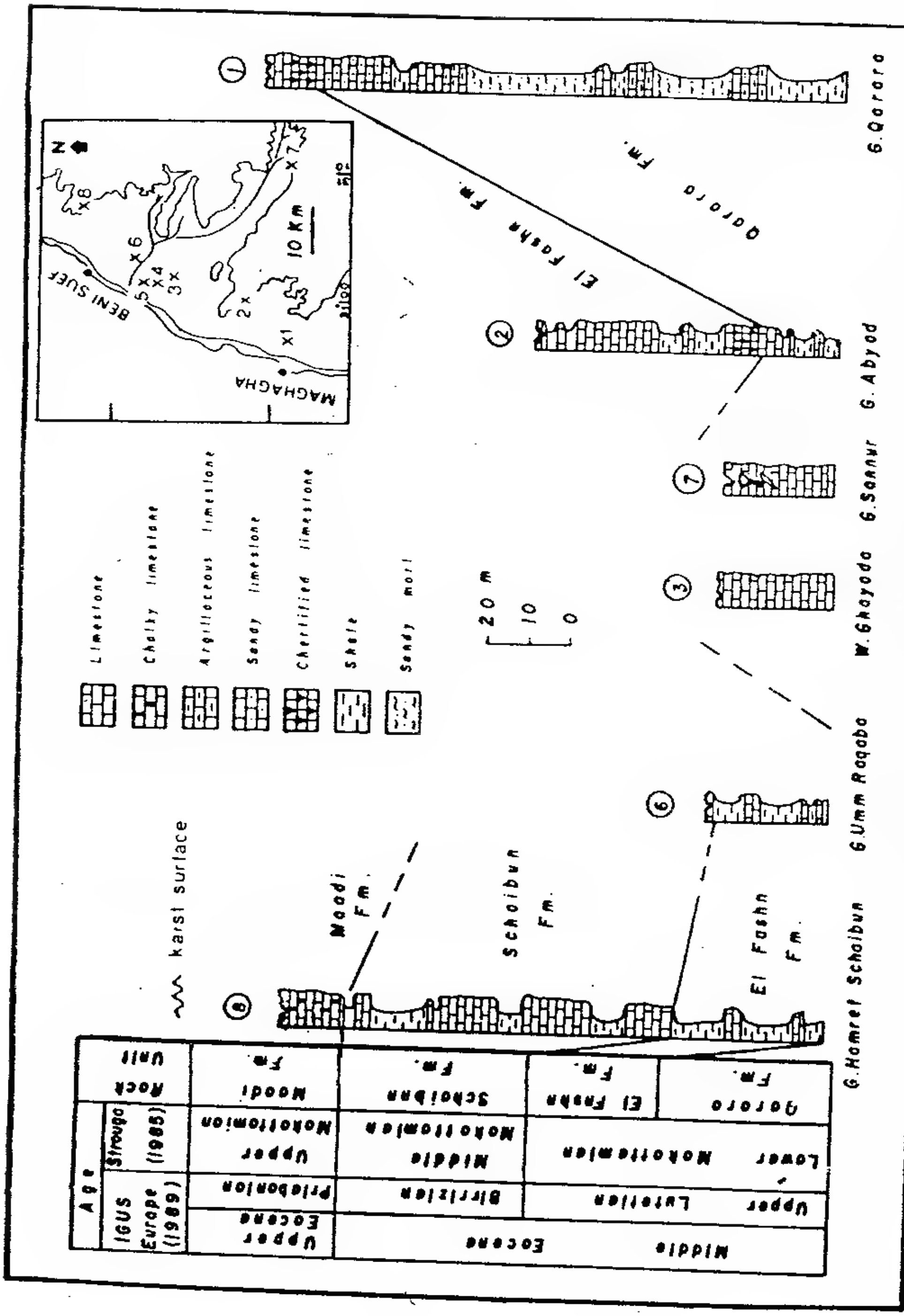
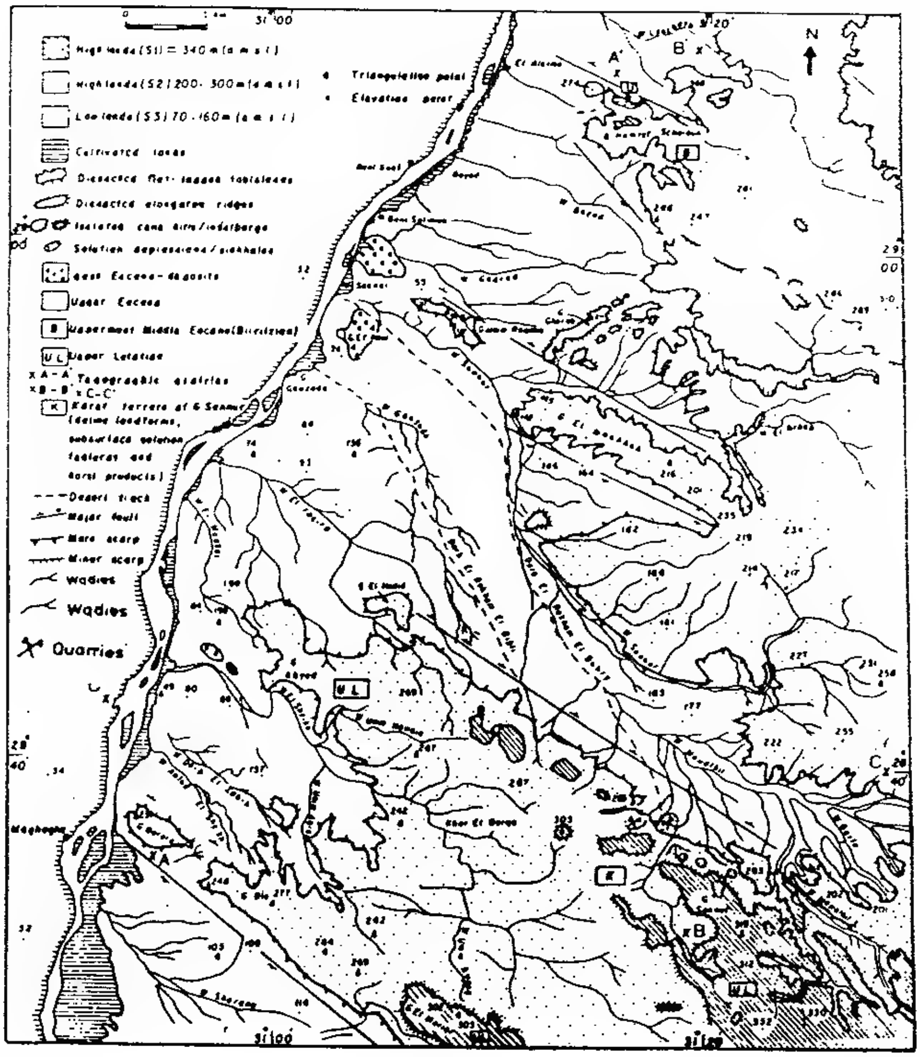


Fig. 2. Correlation chart along the measured sections in the study area.

tions. The nomenclature of these units is based on the accepted formal scheme of Bishay (1966), applied by Omara *et al.* (1977, 1978); Bassiouni *et al.* (1980); Soliman and Korany (1980); Strougo and Azab (1982); Mansour and Philobbos (1983); Strougo *et al.* (1984); Strougo (1985 a,b); and Strougo and Boukhary (1987) among others. The Middle Eocene sequences (Qarara and El Fash formations) cover most of the study area (Figs. 2&3), while the



3.General geomorphic map of Gabal Homret Shaibun-Gabal Sannur area.

Upper Middle and Upper Eocene rocks (Schaibun and Maadi formations, respectively) are recorded only at G. Homret Schaibun in the north (Figs. 2&3). The middle carbonate unit of the Qarara Formation forms the main exposures of G. Sannur and G. Ghayada areas, where it consists mainly of homogeneous nummulitic limestones showing typical karst features. The effect of intensive subaerial diagenesis, that controlled, to a large extent, the distribution, characters and appearance of the exposed Eocene sequences was not given due attention by most of the previous authors and appears to be responsible for some of the discrepancies between the above mentioned lithostratigraphic schemes.

During the late Eocene-Oligocene regression, the study area was pronouncedly uplifted, which resulted in a set of NW-SE faults. The developed joint sets show NE, ENE, NW, WNW and E-W directions. In the course of Pliocene sea transgression, a gulf was developed and Pliocene marine sediments are recorded at G. Umm Raqaba. The exposed carbonates along the Nile Valley were covered by Quaternary deposits formed mainly of fanglomerates, wadi fills and talus. The Nile sediments covered the lowest erosion surface and built up the cultivated stretch.

PHYSIOGRAPHY

The study area is characterized by three main paleoerosion surfaces of different altitudes, demarcated by paleokarst (duricrust) profiles (Figs. 3,4 and Pl. 1a). Each of these surfaces has its own morphologic characters and karst products. The recognition of these surfaces is based on the definition of Faniran and Jeje (1983) for paleoerosion surfaces. The quantitative characters of the drainage basins of these surfaces (Fig. 5) are summarized in Table 1.

1. First Erosion Surface (S 1, Highlands, 340 m a.s.l.)

The oldest (highest) surface covers up to 10% of the study area. It is well represented in G. Homret Schaibun and G. Sannur by accordant summits of relict duricrusted landforms (Figs. 3&4). It is separated from the surrounding lower surface (S2) by scarps of erosional nature, exhibiting the typical hillside slope elements of king (1962): a) convexity at the top; b) free face of duricrust with slope angle up to 80°; c) debris slope with slope angle up to 30°, covered y duricrust boulders and blocks, and d) lower concavity with average slope

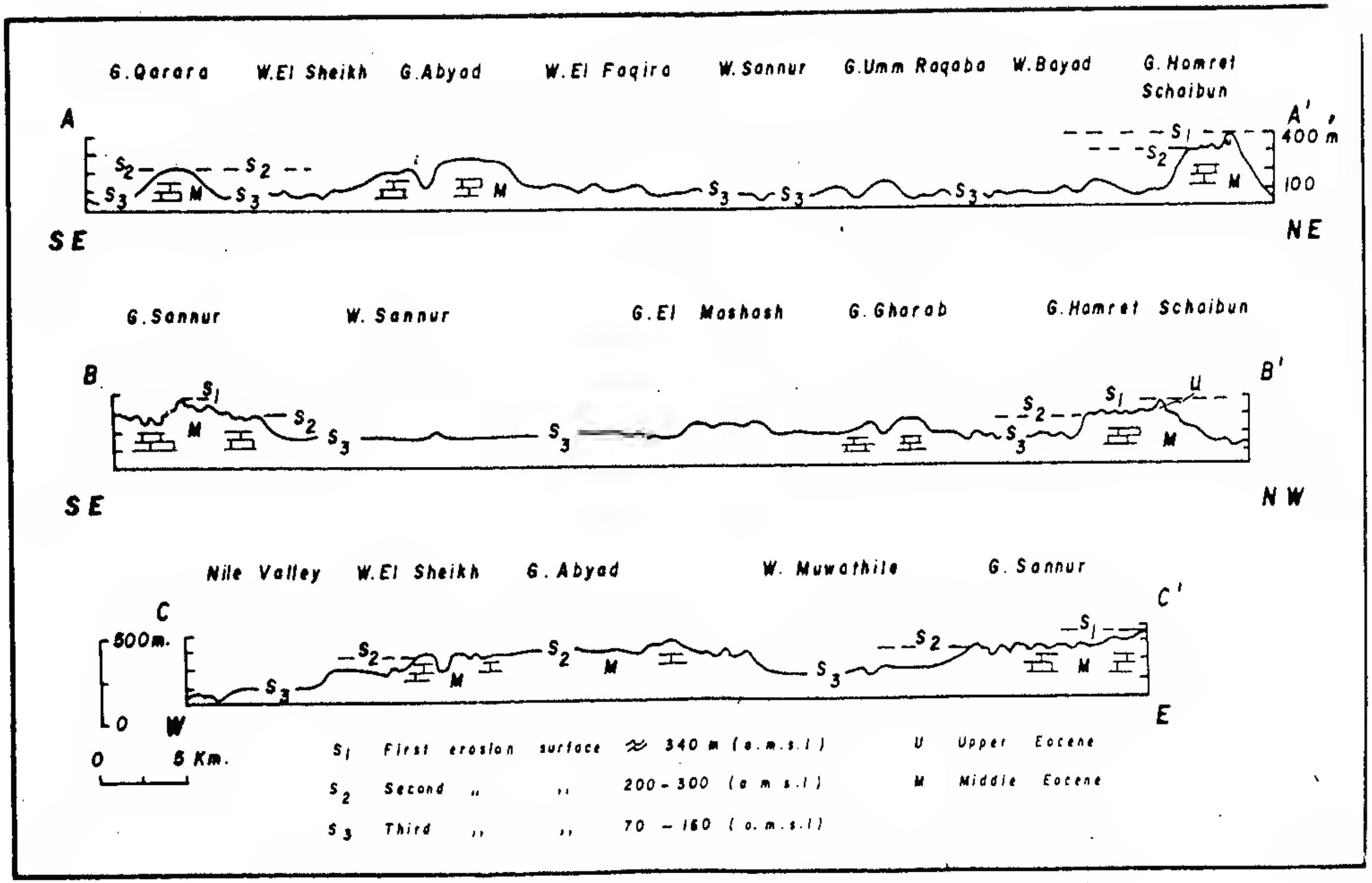


Fig. 4. Topographic profiles through the study area showing the recognized paleoerosion surfaces (S1, S2, S3). (for location see Figure 2).

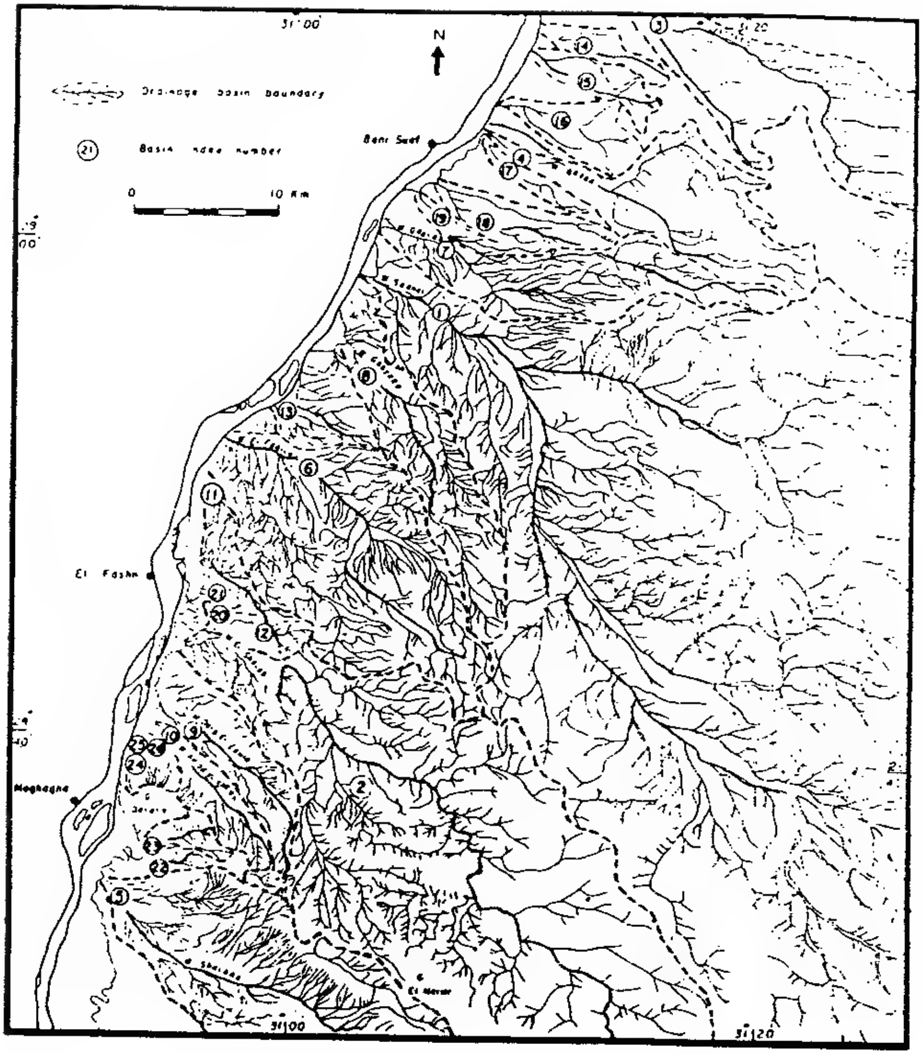


Fig. 5.Drainage map of the study area.

Erosion Surface	Index No. (Fig.5)	Main Stream Order	Total Stream Length (L,km)	Basin Area (A, km²)	Drainage Density (D = L/A)	W.Rb.	Circularity (C)	Elongation (E)	C/E	Geomorphic Interpretation
S_1	1	6	1206	134	0.90	4.14	0.45	0.8	C < E	D = 0.9 (coarse texture) reflecting a steep impervious area in a region of high precipitation (humid); W.Rb = 4.14 lying in the range of natural streams; C < E reflecting the effect of lithology and topography on the basin development.
S_2	2	6	729	507	1.43	4.36	0.65	0.18	C > E	D = 1.43, 0.9 (coarse texture) indicating that both wadies have cut in impervious rocks on an area of high precipitation; W.Rb. lying in the range of natural streams; C E denoting the effect of lithology on the basin development.
	3	4	119	134	0.90	4.28	0.56	0.18	C > E	
S_3	4	4	103	103	1.00	4.11	0.42	0.20	C > E	D = (0.82 to 5) falling in the coarse density category characterizing area of permeable rocks with low rain fall; Small variation in W.Rb. from one basin to other (in 19 basins) is attributed to differences in the shape of the stream networks and reflects natural stream systems. The relatively high values for the another four basins indicate structural effect. (C E or C E indicating the effect of topography, lithology and structure on the basin development). W.Rb= Weighted mean bifurcation ratio
	5	5	327	150	2.18	3.76	0.45	1.25	C < E	
	6	6	327	229	2.28	4.22	0.44	1.38	C < E	
	7	5	145	79	1.84	4.57	0.38	0.20	C > E	
	8	4	124	57	2.15	4.26	0.31	0.63	C < E	
	9	4	99	38	2.57	4.26	0.16	0.42	C < E	
	10	3	74	26	2.86	5.00	0.28	1.15	C < E	
	11	4	96	19	5.00	5.70	0.41	0.20	C > E	
	12	4	25	13	1.90	3.56	0.61	0.42	C < E	
	13	2	52	28	1.80	4.67	1.39	0.73	C > E	
	14	2	16	14	1.10	4.00	6.58	0.22	C > E	
	15	2	20	17	1.10	7.00	0.62	0.23	C > E	
	16	2	23	27	0.82	11.00	0.82	0.20	C > E	
	17	3	9	10	0.89	2.00	0.51	0.33	C > E	
	18	2	31	28	1.12	8.52	0.55	0.22	C > E	
	19	3	15	11	1.30	4.00	0.40	0.16	C > E	
	20	3	6	3	1.42	4.40	0.79	0.87	C > E	
	21	3	5	3	1.58	2.70	0.61	0.79	C < E	
	22	3	11	6	1.70	3.50	0.54	0.24	C > E	
	23	3	25	10	2.33	4.50	0.41	0.44	C < E	
	24	3	5	3	1.70	2.00	0.59	0.98	C < E	
	25	3	9	3	2.74	2.75	0.64	0.36	C > E	
	26	3	10	4	2.08	3.00	0.20	0.20	C = E	

Tabia 1 Summary of tha Quantitativa Analysas of Drainaga Basins Associated with the Thraa Paleoerosion Surfaces (Based on tha Calculation Mathods and Intarpretations of Horton (1932 and 1945); Langbain (1947); Smith (1950) and Strahiar (1957).

angle less than 10°. The surficial duricrust of this surface, up to 8 m thick, is flat-lying with a constant altitude of about 340 m a.s.l. Where dissected, it gives rise to etchsurfaces as flat-topped tablelands, mesas, buttes, conehills and towers (Fig. 6 ; Pl. 1a,b,c). At G. Homret Shaibun, the Upper Eocene

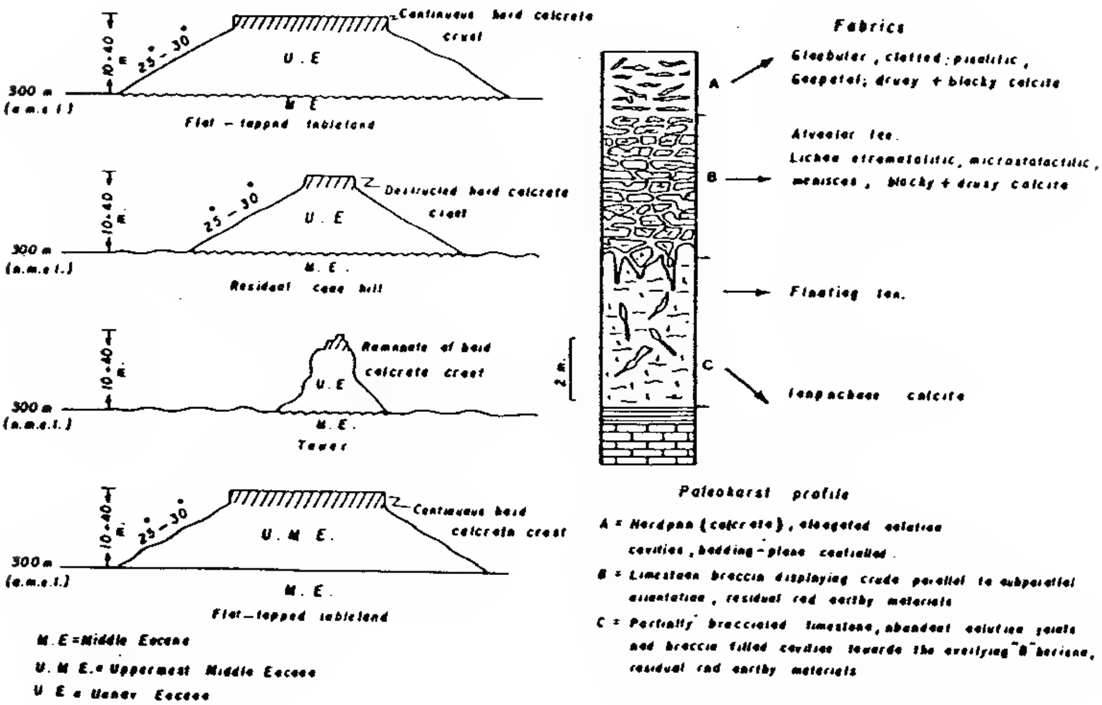


Fig. 6.Sketch diagrams showing the paleokarst features and profile of the first erosion surface.

carbonates (Maadi Formation) and the underlying Middle Eocene Schaibun Formation are the main constituents of these duricrusted landforms, while at G. Sannur area they are built up of the Middle Eocene Qarara Formation. The duricrust profile (Fig. 6&Pl. 1d) consists of : a) a lower horizon of cavernous and brecciated country rocks ; b) a middle horizon of limestone breccia fragments either cemented by crustified, gravitational and blocky calcite or embedded in residual red earthy materials, and c) an upper hard cap of calcrete, cementing highly subdued and fragmented limestone (locally known as "Travertine"). In some places, the relict landforms are covered by surficial fluvial deposits. Around W. El Khasf, W. Umm Arqub and W. Umm Ashara (tributaries of W. Sannur), large scale duricrusted tablelands are highly interrupted by sinkholes and dolines (Fig. 7). Several sinkholes occur close to each other, the coalescence of which may from a large composite solution doline of irregular outline. Some are arranged in parallel lines coniciding with the NW-SE fracture sets, indicating structural control, while others appear to be formed by the collapse of underground openings (caves). The dolines often include remnants of host carbonates in the form of isolated conehills, rising abruptly from their floors. The floors of most large-scale dolines extend downwards to the S2 surface. The joining dolines, resulting from continuous widening through parallel recess of their walls, led to the progressive consumption of the paleotopographic highs of the S1 surface. Consequently, detached and duricrusted interfluves prevail, with or without solution depressions (Fig. 7).

The duricrust profile of S1 surface is a good indication of the stage of erosion of an old erosion cycle. It represents the results of paleokarstification that prevailed during the general lowering of the landscape under humid conditions. The hardening of this profile occurred under arid to semiarid climate, either through precipitation of carbonates by capillary rise and evaporation during water table stability, or by organic activity (Gouide, 1973). The lack of evidence that this duricrust profile had been tectonically uplifted after formation, advocates its development on lowlands. On the other hand, the karst conehills, towers, sinkholes and dolines are typical landforms of tropical to subtropical humid conditions (Ritter, 1978; Jakucs, 1977; Faniran and Jeje, 1983; Ollier, 1984 and Trudgill, 1985 among others). Thus, the situation of the present duricrust profile on hill tops can be attributed to subsequent inversion in the general relief during post-duricrust events of fluvial action and etchplanation processes.

Fig. 7.Karst terrain of Gabal Sannur area.

2. Second Erosion Surface (S2, Intermediate Highlands, 200-300 m a.s.l.)

This surface covers about 70% of the study area and represents the watershed of W. El Sheikh and W. Lyschayb. A substantial part of this surface has been reduced to an undulating plain with occasional upstanding rounded hillocks (hummocks) and remnants of S1 surface.

At G. Qarara, carbonate pavements covered by a thin veneer of silcrete are ubiquitous allover this surface. The surficial silcrete grades downward into highly cavernous and silicified carbonates. At G. Homret Shaibun, G. El Mashash and G. Umm Raqaba, the S2 surface is covered by carbonate rubble forming a hard cap of dissected duricrust. The rubble, up to 8 m thick, was formed by *in situ* solution and fragmentation of the country rocks along bedding planes and joints. It is either cemented by calcite or embedded in matrix of calcareous mud with patches of earthy limonitic materials. Occasionally, the duricrust rubble is partially or completely stripped, resulting in the gradual exposure of the underlying rocks. The exposed rocks are highly diversified by solution cavities filled with calcrete crusts and geopetal clastic sediments.

In G. Sannur area (Fig. 7), the S2 surface is mantled by a thick cover of terra-rossa mixed with calcrete. These subaerial soils are underlain by a considerable thickness of highly disintegrated and collapsed limestones which belong to the Middle Eocene Qarara Formation. This area is highly dominated by surface to subsurface solution forms of various shapes and diameters, commonly connected with large scale solution caves below. The karst profile can be subdivided into three distinguished hroizons: an upper horizon of terra-rossa and calcrete, a subsoil horizon and a lower horizon of fresh or weathered parent rocks. These are recognized in outcrops and quarry faces as well as from available subsurface caves. The morphologic and compositional characters of the S2 surface and its karst profile are illustrated in Figure 8.

a. Upper Horizon

The horizon corresponds to the infilteration upper vadose zone of the ideal authigenic karst profile of Esteban and Klappa (1983). It is characterized by the predominance of surface solution features and a thick cover of terra-rossa and calcrete deposits. The initial stage of dissolution is displayed by vertical

and inclined solution joints or karren, cutting across the hummocks and commonly filled with crustified calcite and red soils (Pl. 1e). Continuous widening of joints forms a network pattern resulting into the gradual brecciation of carbonates and the consequent formation of limestone rubble (Karst rubble breccia, Meyers, 1988) embedded in red soils (Pl. 1 f&g). Near surface cavities are also developed along the widened joints or along several levels parallel to the bedding planes (Pl. 1 h). The cave fills include matrix-supported gravel to cobble size carbonate fragments, terra-rossa with calcrete nodules, large columnar calcite crystals with geopetal clastic deposits and (or) stromatactis calcareous layers of calcrete facies.

The terra-rossa and calcrete deposits are widespread on the plained surfaces between the hummocks in the form of disconnected lenses of irregular outlines. They also occur above the occasional solution channels, sinkholes and dolines, where they are often overlain by greenish brown to green alluvium, up to 2 m thick (Pl. 2 a&b). The thickness ranges between 2 to 8 m and up to 12 m above the depression (Pl. 2 a). They taper away and wedge out towards the surrounding highs. Their surface is more or less smooth and sometimes convex. Lenticular patches of terra-rossa, 1 to 3 m thick, are also present on the floors of some streams. A thin veneer of terra-rossa, with or without calcrete, occurs on the top surface and gentle slopes of the hillocks and topographic highs. They may also envelope the bedrock relief with a maximum thickness of 30 cm. This soil cover is commonly stripped away, exposing the underlying carbonate rubble and breccia. The terra-rossa consists mainly of red earthy materials of iron sesquioxides and clays mixed with silt to sand-sized quartz grains, plant tissues and root molds. It often includes limestone fragments of sand, pebble and boulder sizes. Also, *in situ* reddened limestone blocks are not uncommon. Banding and fine lamination are the common sedimentary structures of the terra-rossa. However, they may be massive with irregular pattern. The bedded terra-rossa and the enclosed blocks reflect the original bedding nature of the karstified bedrocks (Pl. 2 b). The red terra-rossa is commonly intercalated with calcrete layers and includes calcrete nodules, glaebules, pisolites and rhizocretions. The relative frequency distribution of both, the red soils and calcrete, varies from place to place.

b. Middle Horizon

This hroizon, 20 to 100 m thick, represents the transitional zone between the overlying infilteration horizon and the underlying parent rocks (Fig. 8). It is

PLATE 1

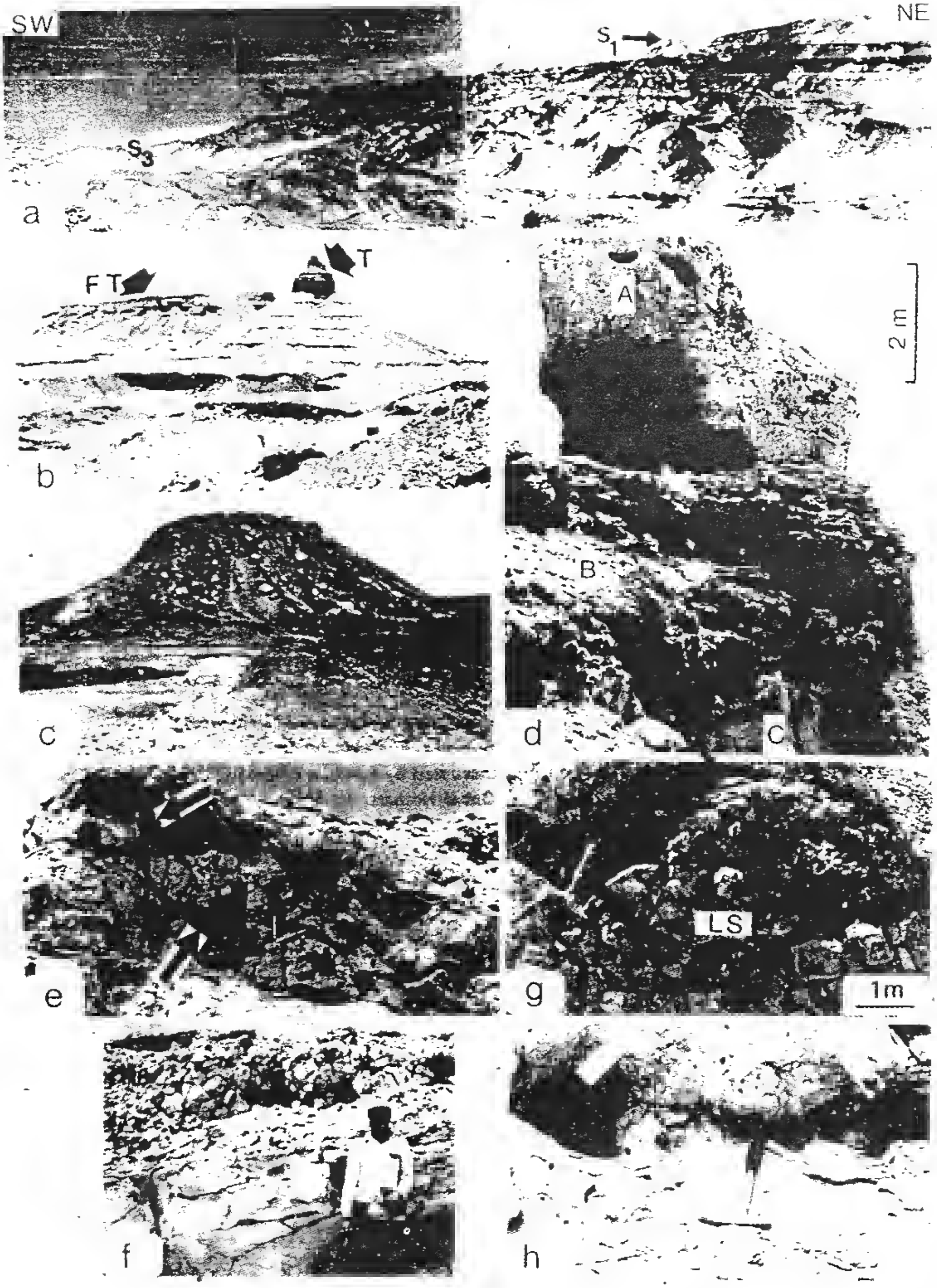


PLATE 1

a) Panoramic view showing minor scarp separating S1 from S2 surface and main scarp seperting S2 from S3 surface; G. Homret Schibun. b) Flat-topped tableland (FT) and karst tower (T) of accordant summits. Tops are encrusted by surficial calcareous duricrust which delineates the first erosion surface (S1), Gabal Homert Schaibun c) Isolated duricrusted conehill as a remnant of the S2 surface S3 surface; G. El Nour. d) Field photograph showing the karst profile of the first erosion surface (S1); G. Homret Schaibun. A = hardpan; B = cavernous and brecciated limestone; C = parent limestone. a) Widened solution joints filled with terra-rossa (arrows). f) Rubble breccia resulting from the continuous dissolution along intersecting joints. g) Red matrix breccia in bedding controlled cavities (arrows). The limestone country rocks around the cavities (LS) are highly brecciated, and reddened. h) Pigeonhole cavities developed along the bedding planes. The walls of the cavities are partially lined with stromatactis calcite (arrows).

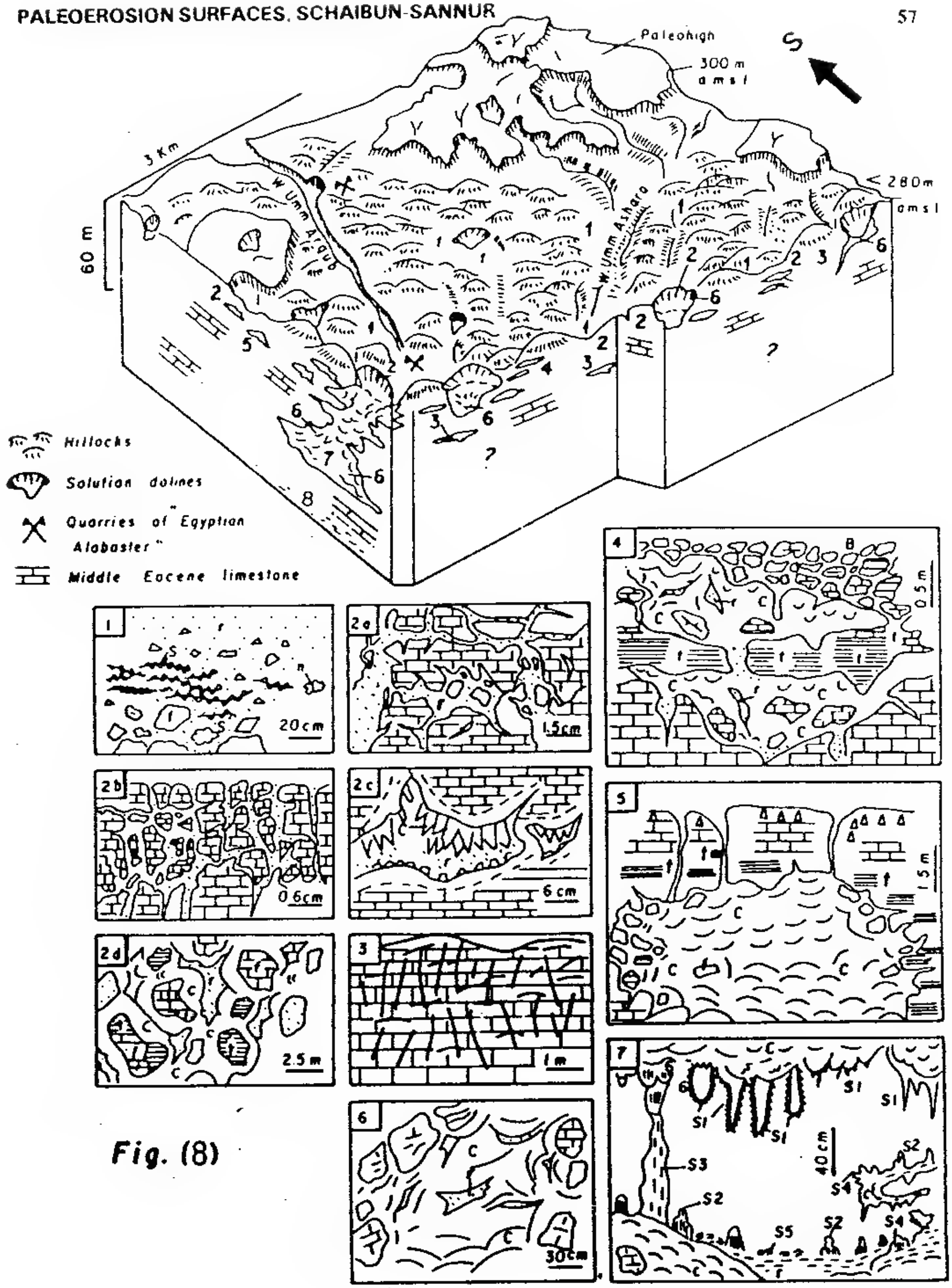

Paleohigh
300 m amsl
280 m amsl
S
3 Km
60 m
W. Umm Argub
W. Umm Asharo
Hillocks
Solution dolines
Quarries of "Egyptian Alabaster"
Middle Eocene limestone
20 cm
1.5 cm
0.5 m
0.6 cm
6 cm
1.5 m
2.5 m
1 m
30 cm
40 cm
S1
S2
S3
S4
S5

Fig. (8)

restricted to the homogenous nummulitic limestones of Qarara Formation with low content of argillaceous matter (up to 1.7%, Soliman and Korany, 1980). The difference in elevation between the lower level of the subaerial terra-rossa deposits and the lower level of W. Sannur tributaries is equivalent to the thickness of this horizon. The rocks of this horizon had been affected by intensive karstification, that resulted in sculpturing, dissolution and alteration of the limestones and the formation of surface to subsurface solution features, subsurface caves and intrakarstic deposits. All the solution features and karst deposits of this horizon are similar to those of the lower vadose percolation zone and the upper lenticular phreatic zone of the idealized authigenic karst profile of Esteban and Klappa (1983).

Surface to Subsurface Solution Features: These include sinkholes and dolines. They are common at the downstreams as points of sinking, randomly distributed within the upstanding hillocks. The sinkholes, tabular and (or) funnel in shape, 2 to 15 m wide and up to 30 m deep, are usually aligned along the main scarp separating the S2 and S3 surfaces, where they are partially or completely filled with intrakarstic deposits. Two types of dolines are recognized : solution dolines and collapse dolines. The former are the result of

Figure 8

Block diegram of the karst profile of second erosion surfece et G. Sennur area (vertical scele is exaggsreted). 1) Tsrra-rossa (r); with limestone fragments (f); elgal stromatactis (S); end clacareous nodules (n). 2e) Anastomosing solution joints and cavitiss filled with tarra-rossa (r); 2b) Advanced stage of brecciation and formation of rubbles end red matrix breccia; 2c) geopetal intemel sediments consisting of terra-rossa (r) and isopachoue bladed calcite (c); 2d) cockada structure of limestone fragments (i), highly altered to rottsnstona (t), rncrusted by crustified calcite (c) and terra-rossa (r). 3) Highly fractured limsstona, the fracturss are filled with red earthy rssidus (tsrra-rossa). 4) Bedding controlled csvities filled with collapse breccie (B), crustified calcite (c) end red terra-rossa (r); the limestone ls completely altered to rottenstone (t). 5) Deeper solution cavity connected with ths surface by vsrtical solution joints and completely filled with crusified calcareous layers (c) with collapse breccie. Aiteretion of the host limestone into rottenstone is common along the internal walls of the cavity.8) Internal sediments of deeper cavities consisting of collspse breccia, calcaroue crustified layers (c) end red sarthy residue (r). 7) Cavs fills (epeleotheme): C= flowstones sheets and crusts, capping ths walls, floors end roofs of the cavity; S1-S5 = stalsctitss and stalagmites; S1 = soda straw end carrot-like stalactites; S2= smooth stalagmites and nodulss; S3= coulumns or pendants; S4 = sparry trees and bunches; S5= curvillineer calcareous crust within red soils (r). 8) Pertent rocks (limestone end shale).

dissolution along joints and fractures. They are conical in shape, range in width from 20 to 30 m and in depth from 30 to 50 m, with 30° to 40° side slope angles. The doline walls are highly fractured and brecciated. Dissolution along the fractures separates the host rocks into blocks and cobbles encrusted by concentric crustified calcite bands forming cockade texture (Pl. 2 c&d). The continuous widening and deepening of these dolines led, through the connection of neighbouring ones, into the fromation of large scale depressions (poljes or uvalas) with a maximum diameter of 400 m. These large depressions are widely distributed along the watershed area of W. El Sheikh at G. El Merier and G. Sannur. They have flat floors, commonly traversed by streams. The enclosing limestone walls have footslopes inclined at 20° to 30° and rising 70 m above the depression floors. Remnants of terra-rossa and calcareous cursts are recorded on the floors of some of these depressions. The development of such large scale depressions shares in the consumption of the S2 surface and formation of the S3 surface. Collapse dolines are recorded at the large "alabaster" quarries (e.g. quarries Nos. 51, 52, 53, and 55). They are of cylindrical shape and range in width from 50 to 75 m with a depth up to 100 m. Most of these dolines are filled with collapse breccia, that resulted from the collapse of roofs of former subsurface caves and doline wells. Continuous collapsing of roofs and retreat of doline walls gave rise to large steep walled bowl-shaped depressions.

The soil cover associated with the sinkholes and dolines played an improtant role in their formation. Subaerial pedogenesis increases the pCo_2 and accentuates the corrosion of the underlying limestones by infilterating soil solution rich in Co_2 (Trudgill, 1985). The collapse dolines represent the connection of surface and subsurface denudation with roof collapse.

Subsurface Solution Features: a) solution cavities of elongated form, resulting from corrosion and widening of vertical joints by infilterating solutions. Such cavities, up to 2 m wide and 20 m long, are commonly connected with the upper terra-rossa horizon through vertical or inclined joints, solution shafts or sinkholes; b) solution cavities developed along bedding planes. They are elongated and (or) circular in shape with roofs usually convex upwards, indicating corrosion under phreatic or phreatic to vadose condition (Bogli, 1960). The long diameter of the individual cavity ranges from a few centimeters to 5 m. The cavities are commonly connected laterally and vertically to form huge caves, about 10 m in height, and extend laterally for more than 30 m; and c) solution caves developed along the intersection of both bedding planes and vertical joints, up to 60 m high, 50 m wide and 300 m long. The cave shape is largely controlled by the network pattern of fracture sets, but

usually it tapers upward and widens downward. The walls and roofs are highly fractured, brecciated and ferruginated as a result of dissolution by meteoric water (Pl. 2e). The cave walls and roofs are dominated by scallop features (Pl. 3a). Scallops on the roofs reflect a phreatic regime, while those on the walls indicate vadose condition (Jennings, 1985 and Trudgill, 1985).

Intrakarstic Deposits (Doline and Cave Fills): The studied dolines and caves include different autochthonous and allochthonous deposits (Fig. 8). The allochthonous sediments consist of silt and clay mixed with red ochers, 1 to 2 m thick, coating walls, ceilings and floors. They show fine lamination alternating with thin autochthonous calcite laminae and suggest deposition from floods or pulsed flows. In some places, the deposits are massive; lack lamination suggesting decantation from a homogeneous suspension. These are widespread on cave floors and reach up to 50 cm in thickness. They commonly include calcite glaebules, laminae, and concretions, 2 mm to 5 cm in diameter, which represent diagenetic crystallization during dewatering and degasing regimes in the cave environment.

The autochthonous deposits are differentiated into : autochthonous clastics and authochthonous precipitates (speleothems). The autochthonous clastics mainly result from the partial or complete breakdown and collapse of bedrock from walls and ceilings. As a result, poorly sorted deposits consisting of a mixture of clasts accumulate as piles on the cave floors. These are either grain supported with crustified calcite cement, or matrix supported when embedded in red earthy materials forming red matrix breccia. Clasts may be held in position along walls and ceilings by crustified calcite bands (Pl. 2f). Based on the classification of White and White (1969), these debris could be differentiated into : 1) blocks, where fragments consist of more than one bed remaining as a coherent unit. The single block is 3 to 5 m thick and 2 to 10 m long; 2) slabs composed of a single broken bed, 10 to 50 cm thick and up to one meter long; and 3) chips, where the beds are fragmented into angular clasts of gravel to boulder sizes. The formation of these clasts is attributed to the following: 1) removal of the bouyant support of water when a phreatic cave is drained; 2) undermining of a wall or overwidening of a roof by lateral vadose stream erosion ; and 3) solution along fractures within falling masses which reduces their bonding. The precipitation of autochthonous crustified calcite, binding these fragments, is accompanied by simultaneous dissolution

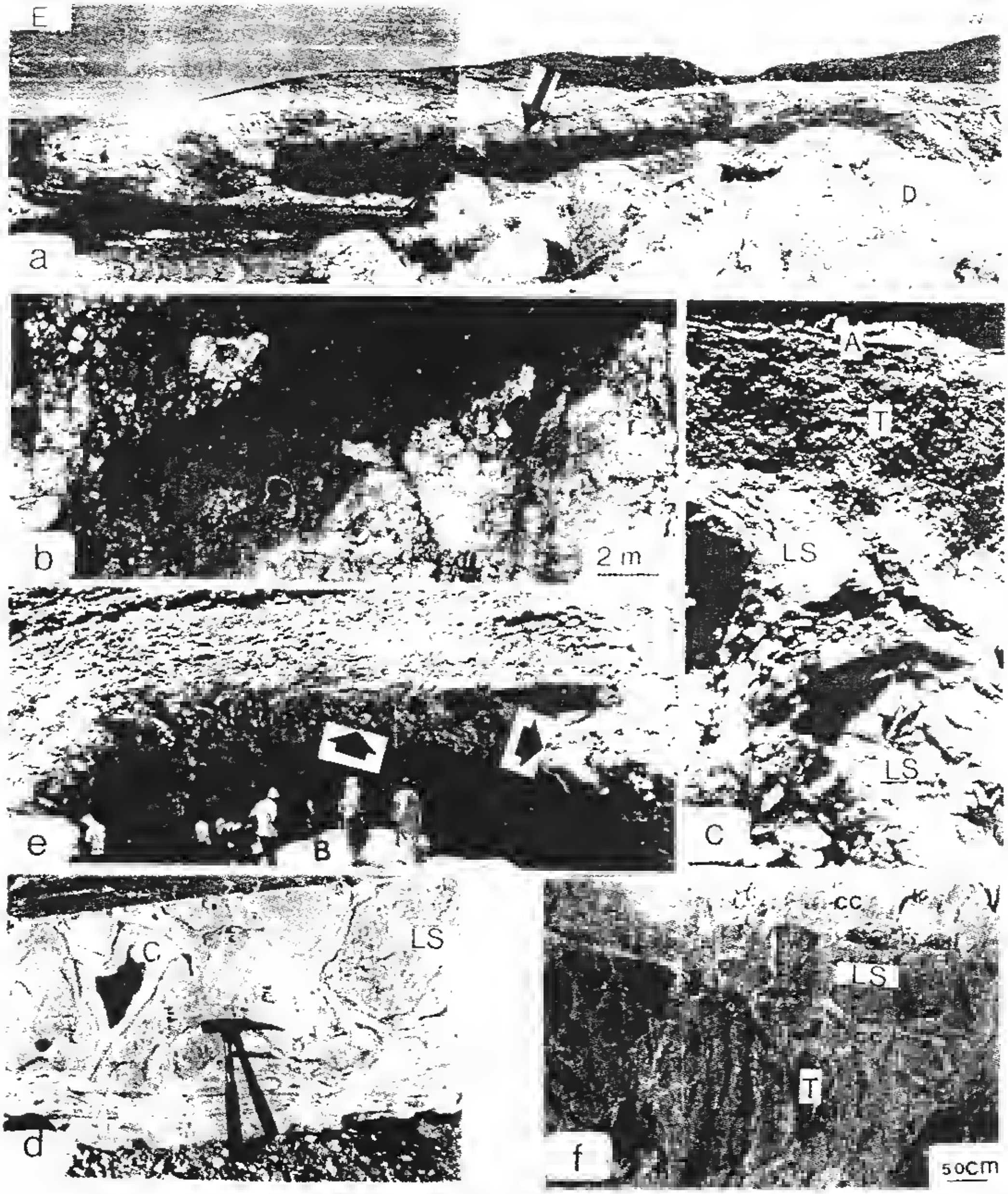


PLATE 2

a) Top view of large scale solution dolina with thick soil cover (arrow), Quarry No. 54, G. Sannur area. b) Terra-rossa infiltrating highly weathered limestone bedrock. Terra-rossa is accumulated along the fractures marking alteration of the parent limestones into rottenstone. c) Wall of solution dolina retaining the original bedding of limestone (LS). Notice, the presence of crustified calcite and terra-rossa cover (T), A = alluvium. d) Cockade structure along the wall of solution dolina showing collapse breccia (LS) with crustified calcite (C) around fragments, red soils accumulated in between. e) Large scale solution cave developed along bedding plane. Notice, brecciation along the roof (arrows). The cave is filled with crustified calcite and terra rossa. f) Cave fills showing collapse breccia fragments surrounded by crustified calcite (cc) and terra-rossa (T).

and corrosion of the edges to form subrounded to well rounded clasts with accumulation of residual red earths within the pore spaces. The resulting rock is conglomerate-like in appearance.

The speleothems are the chief precipitates by volume, and the most significant autochthone in terms of the paleoenvironmental information that could be gained. They are composed of calcite precipitated through diffusion of Co_2 from water to the cave atmosphere. Calcite shows variable forms of syntaxial overgrowths growing on cracked, brecciated and reddened rocks or pre-existing calcite crystals or crusts. The speleothems belong to the following genetic types:

1. Speleothems formed by intermittent sheet flows: resulting in linear oscillating ripples on roofs and walls and give rise to scallops under phreatic and vadose conditions (Pl. 3a). The scallops show crumpled or gently curved sequences of alternating fine crystalline with milky to yellow coarse crystalline calcite bands symmetrically growing on the opposite sides of the cave. The interspaces between the rhythmic sets are filled with residual red earthy materials. The alternation of fine and coarse crystalline calcite reflects rapid and slow crystallization rates controlled by rhythmic changes in the pCO_2 of the water and cave atmosphere. The geometric arrangement of these bands is correlated with the diagenetic crystallization rhythmites of a partially closed system (Fontboté and Amstutz 1980). These calcite rhythmites are known as "Egyptian Alabaster" exploited at G. Sannur and neighbouring areas.

2. Drip water stalactites: formed by dripping flows along vertical or inclined fractures and joints cutting across the aforementioned crustified calcite (Pl. 3 b-f). They are displayed by downward growing stalactites that range in length from a few millimeters to 6 m, with a diameter up to 1 m. Straw and carrot-like stalactites (Pl. 3e) which build as hollow or solid cylindrical tubes, up to 25 cm in diameter, are also common. The film of water flowing outside the cylindrical tubes deposits radiating crystals which result in a tree ring structure. The small downward shift of percolating water along joints gives rise to stalactites of lotus and pear-shape (Pl. 3c), sparry trees and bunches, consisting of radial fibrous calcite crystals of flower arrangement and pipelike stalactites of variable diameters. Curtain or screen-like stalactites (Pl. 3b 2d) of radially stacked drip pipes of calcite crystals, which suggest deposition from sheet flow along vertical joints and fractures are also common.

3. Drip impact water stalagmites: drops falling on the floor build upward stalagmites of variable diameter and shape. Uiformity in drip rates and cave atmosphere reults in constant deposition and uniform diameter stalagmites. A conical form suggests a decreasing rate of deposition. The varying rates of deposition form tier-shaped cake stalagmites (Pl. 3c).

4. Columns: the connection between stalacities and stalagmites results in columns or pendants characterized by tree-ring structure (Pl. 3g).

5. Linear calcite of intermittent flows: at the end of sheet flow, curvilinear calcite forms on the cave floors. The interlaminae spaces are filled with allochthonous red earthy materials including calcite noudules and pisolites (Pl. 3 h,i).

c. Lower Horizon (Partially Altered Parent Rocks)

A transitional contact is observed between the middle subsoil horizon and the underlying parent rocks. Petrographically, the intact limestones are represented by mudstone, algal nummulitic packstone and grainstone associations. Along the contact with the overlying horizon, the country rocks are highly diversified by solution joints and cavities and show shades of gray, buff and red colouration as a result of dissolution and concentration of residual red soils and clays. Ultimately, they become completely altered to weakly cemented sponge-like rottenstone (Bucchino) which represents a transitional stage between the unweathered rocks and red soils as the end product. Intensive reddening of the parent rocks masks most of the original textures, however, the original bedding is still preserved. The alteration and excavation features decrease in frequency downwards until the fresh limestone and shale interbeds of the Qarara Formation are reached.

The development of the above described typical karst profile with the silcrete and calcrete duricrusts, duricrust rubble and the accumulation of intrakarstic deposits indicates that the erosion cycle responsible for the formation of the S2 surface had reached its senile (old) age. The S2 surface is incised by streams which may form main broad meandering wadis, that extend to the lower S3 surface. These could be related to rejuvenation during subsequent fluvial periods. Wadi Sannur and its tributaries cut through the S2 surface and appear to have developed their courses by continuous widening and deepening towards the Nile Valley. Wadi El Sheikh continues to swing from side to side resulting in a large deepened entrenched meander. Advocating the

PLATE 3

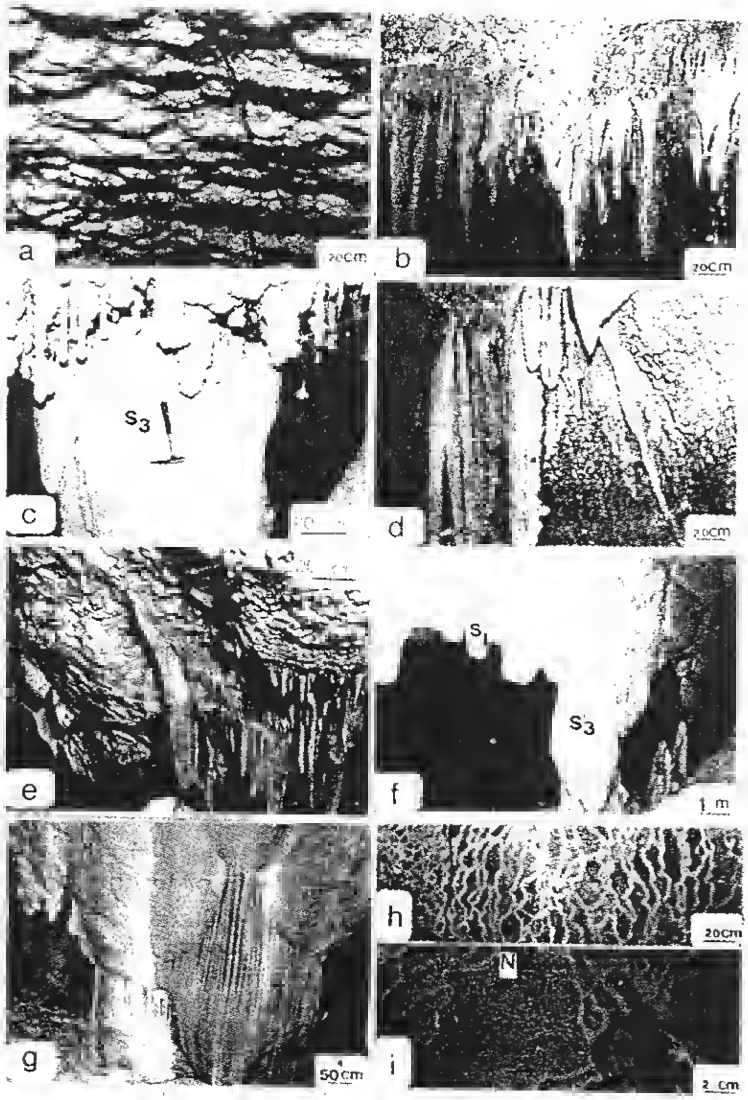


PLATE 3

a) The roof of a large scale subsufrac cave showing scallops. b) Curtain-shaped stalactites. c) Lotus-shaped stalactites (S1) and column (S3). d) Stalactites developed along vertical joints with calcite nodules growing on the surface. e) Carrot soda straw stalactites growing from roff and along vertical joints. f) Stalactite showing tree-ring structure. h) Allochthonuous red earthy materials (dark) and autochthonous curvilinear calcite (clear) deposited on the floor of solution caves. i) Close up view of (h) showing autochthonous calcite nodules and concretions (N) with allochthonous red earths.

rejuvenation of meanders and large valleys of the S2 surface, is the occurrence of the well developed terraces in W. El Sheikh and W. Sannur with breaks of slope in the valley sides. The terraces may extend for several tens of meters away from the main scarp and have the same elevation on both sides of the meander of W. El Sheikh and allover W. Sannur. They represent valley floors abandoned by rejuvenation of rivers as they cut down the erosion base level. The rejuvenated terraces were cut into the solid rock and are usually unburied or may consist of a rock bench veneered with a thin layer of alluvium. The main scarp separating the S2 from the lower S3 surface shows the typical four scarp elements. This scarp is structurally controlled as it has been developed along the main NW-SE trending faults and the associated fractures sets (Fig. 3). It has been worn back as a result of successive stages of stream flood corrosion. The lateral corrosion of streams was active at points where upland valleys debouch into the S3 surface. The retreat of the scarp is indicated by: 1) the destruction and stripping of the surficial duricrusts and karst deposits of the S2 surface along the main scarp and valley sides; 2) the development of the four slope elements with nearly similar slope angles for all studied scarps; 3) the sharp angle between the debris slope and the underlying pediment which indicates change in the weathering conditions during the slope retreat; 4) the development of fan shaped embayments such as those of W. Awlad El Sheikh, G. El Mashash and the northern part of G. Homret Schaibun ; 5) continuous trimming back of the spurs between adjacent embayments that led to the retreat of the mountain fronts and gradual reduction of the upland masses of the S2 surface; 6) gradual separation of duricrusted interfluves from the mountain fronts as G. El Hadid and the northwest part of G. Homret Schaibun; 7) gradual consuming up of interfluves and formation of dissected flat-topped tablelands such as G. Um Rawaba and G. Qarara; and 8) formation of unduricrusted small interfluves of conical shape (karst conehills), which appear to have been formed by complete stripping of the duricrust with lateral slope retreat.

3. Third Erosion Surface (S3, Lowlands, 70-160 m a.s.l.)

In a broad sense, the lowlands of the study area could be described as a plain surface rising a few meters above the River Nile flood plain. It is characterized by an undulating relief interrupted by residual duricrusted or unduricrusted conehills and ridge. The S3 surface is usually incised by small and very small drainage basins of dendritic to subdendritic pattern. Wadi

Sannur and W. El Sheikh, which cut deeply through this surface, have their main streams reaching about one kilometer in width and act as a gulf within this erosion surface. The main course of these streams is inherited from the S2 surface. The downstreams are usually filled by a relatively thick succession of fluvial deposits of Quaternary age (Hassan *et al.*, 1987). The uncovered floors of these wide main streams are highly diversified by karren and solution basins with or without a soil cover. The soil may extend for several meters and ranges in thickness from a few centimeters to three meters. It consists of laminated red earthy materials and clays with veinlets of gypsum and anhydrite. Towards the Nile Valley, the main streams are covered by Nile sediments. The presence of karren and solution basins with soil cover and alluvial deposits on the bare limestone of this surface indicates the mature to old stage of the third erosion cycle.

PALEOTOPOGRAPHIC EVOLUTION AND FORMATION OF THE "EGYPTIAN ALABASTER"

Following the post Eocene uplift up to the Pilocene time, the exposed carbonate rocks of the study area were subjected to intensive karstification processes under favourable paleoclimatic conditions during three main paleoerosion cycles. These cycles are manifested by three pre-Nile erosion surfaces, upon which typical deep weathering (karst) profiles are detected. Fach of these cycles starts by humid condition and terminates by semi-arid to arid climate. Post-Pliocene events slightly modified these surfaces to their present-day shape. During the landform evolution, the drainge basins passed through four successive phases, for which local names are used (Fig. 9).

The relicts of the high-lying karst profile of G. Homret Schaibun (S1 surface) reflect the products of the oldest erosion cycle that led to peneplanation of the landscape and the increase of karst profiles thickness characterizing this surface.

The second erosion cycle was responsible for the etching of the S1 surface and related duricrust, continuous lowering of the landscape and formation of the S2 surface (Sannur phase, Fig. 9). These were accomplished through etchplanation, pedimentation and pedogenetic processes that include: 1) incision of W. Sannur and solution sinks (sinkholes and dolines); 2) etching and stripping of S1 surface; 3) restriction and backwearing of the S1 surface through slope retreat, widening and connection of solution sinks and

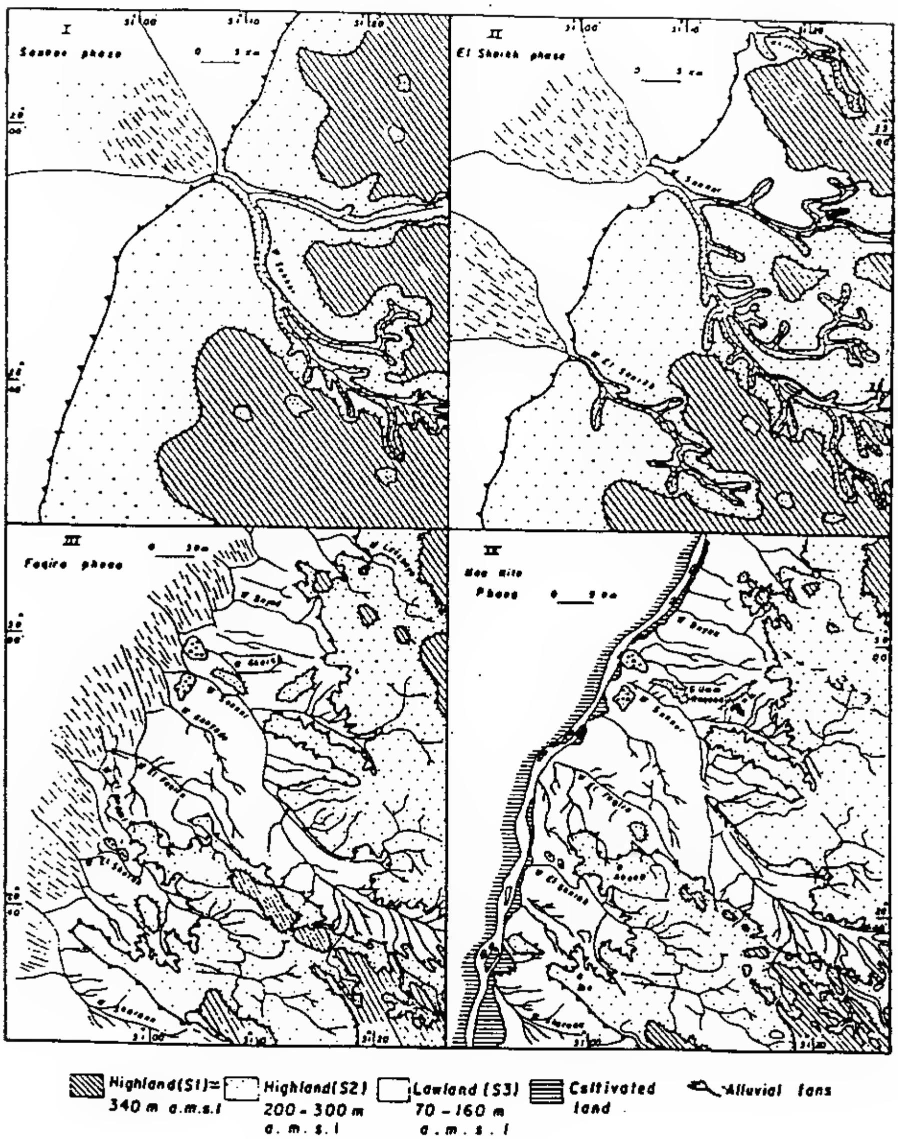


Figure 9

Landform avolution: I (Sannur Phase) = Devalopment of a surficial duricrust (S1 surfece). Incision of W. Sannur, etching, stripping and formation of S2 surface. II (El Shaikh Phase) = Incision of W. El Sheikh and W. Lyschayab, widening, deepining of old streams (W. Sennur), dastruction of S2 surfaca, backwaaring, slope retraat, pedimantation and formation of S3 surface. III (Faqira Phase) = Incision of younger streems, widening, deepening and connaction of older streame, meendaring, backwearing and restriction of S1 end S2 surfacea. Pliocane See trensgrasaion. IV (Neo Nila Phese) = Incision of the Neo Nile.

formation of wide duricrusted interfluves; and 4) continuous widening and deepening of W. Sannur, consumption of the interfluves, pedimentation and formation of the second erosion surface, on which pedogenesis took place and a paleokarst profile was developed.

During the second erosion cycle karstification continued at G. Homert Schaibun and the uppermost Middle Eocene Schaibun Formation (limestone and shale interbeds) was subjected to brecciation during wet seasons, giving rise to rounded clasts cemented by calcite during dry seasons. The alternating lithologic nature of this formation, aided by the development of an indurated duricrust rubble, had a direct effect on the depth of weathering processes in this locality by preventing the continuous downward percolation of meteoric waters. At G. Qarara, the S2 surface is delineated by silcrete duricrust.

At G. Sannur area, the described horizons of the resulting karst profile reflect the karstification stages during its formation. The exposed homogeneous carbonates of the Qarara Formation were subjected to dissolution during the wet seasons of the second erosion cycle. This led to the formation of conspicuous karren as surface runnels and the accumulation of surficial terra-rossa under phreatic-vadose regimes (juvenile stage of karstification, James and Choquette, 1984 and Kerans and Donaldson, 1988). The formed soil cover played an important role in continuous dissolution of the rocks beneath it, under the effect of meteoric water during the mature stage of karstification. Progressive dissolution under soil cover, aided by corrosion along joints and bedding planes, formed sinkholes, dolines and subsurface caves. This modified or even destroyed pre-existing near surface solution forms and increased the thickness of the soil cover.

Deepening of the surrounding wadi floors and lowering of the vadose zone continued with time. Cavity development proceeded deeper until the water table level becomes stable. The development of deeper caves was followed by the deposition of autochthonous and allochthonous deposits when the water level stabilized during the predominantly dry seasons (senile stage of karstification). The surficial calcrete represents a subaerial diagenetic product, crystallizing from carbonated soil solution entrapped within the terra-rossa. The lowering of the water table resulted into the predominance of vadose condition, whence the remaining spaces were filled with dripstones as end products. The long duration of the karstitication processes, the homogeneity of the thick limestones of the Qarara Eormation and the presence of a thick shale section at the base must have helped in the localization and

development of the karst profile with its genetically related products, particularly the "Egyptian Alabaster", in this locality. The impervious nature of the shales favoured the creation of phreatic condition for a long time after each rainy period. The above mentioned karstification stages (Fig. 10) match well with the morphogenetic dissolution phases of Bögli (1960) and the zones of the ideal authigenic karst profile of Esteban and klappa (1983).

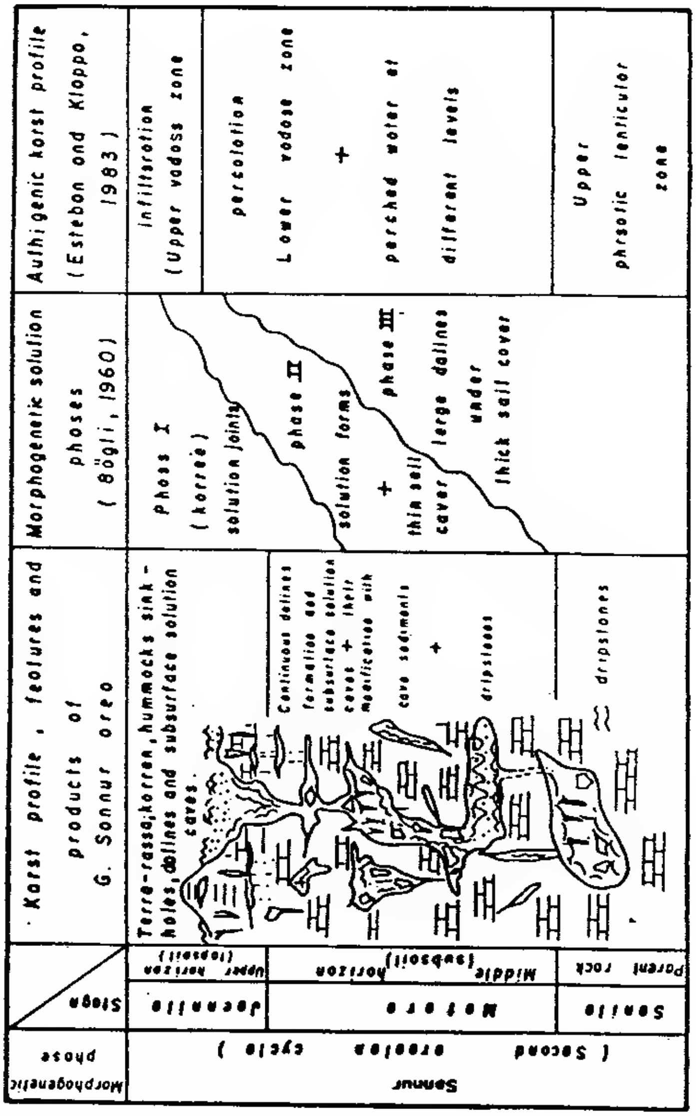


Fig. 10.Evolutionery steges of the kerst profile of the S2 surface.

The S2 surface was further karstified during the third erosion cycle. This is manifested in the incision of Wadis El Sheikh and Lyschayb (El Sheikh phase, Fig. 9), accompanied by the continuous etching and stripping of the pre-existing karst profile, rejuvenation of older karst features, backwearing, consumption of the interfluves through streams and finally formation of the S3 surface.

During Faqira phase (Fig. 9), the S3 surface was incised by younger small and very small basins. Also widening, deepening and connection of older streams took place in addition to backwearing and restriction of the S1 and S2 surfaces. In the course of the Pliocene sea transgression, a gulf was developed where its sediments covered the S3 surface at Um Raqaba. During the post Pliocene regression, the incision of the Neo Nile (Said, 1981) started and its flood plain deposits covered the northwestern margins of the S3 surface (Neo Nile phase, Fig. 9).

The karsitification processes did not run in a simple way, but were accompanied with or affected by intermittent flows, fluctuations of the water table and the presence of perched water in the percolated lower vadose zone, either during the resposible erosion cycle or later rejuvenation through the rainy periods of the succeeding cycle (cycles).

DISCUSSION AND CONCLUSIONS

The exposed Middle and Upper Eocene successions of the G. Shaibun-G. Sannur area were subjected to intensive deep weathering processes, during three pre-Nile erosion cycles. These are recognized by three paleoerosion surfaces of different altitudes. The erosion cycles that involved etchplanation, pedimentation, karstification, pedogenesis and diagenesis, resulted in the continuous lowering and backwearing of the landscape. Typical karst landforms and karst profiles with surficial soils and subsurface karst precipitates occur. The exploitable "Egyptian Alabaster", "Travertine" and "Bucchino" of this area are karst produts representing either hardpan or calcrete crust (the Travertine of G. Homret Shaihun), doline or cave fills (the "Egyptian Alabaster" of G. Sannur area) or altered wall rock varieties ("Bucchino").

The factors, that control the distribution, thickness, and quality of the karst products, particularly the "Egyptian Alabaster" can be summarized as follows:

1. The presece of thick homogenous limestone sequence with low terrigeneous content. Kamel *et al.* (1990) believed that the "Egyptian Alabaster" is not confined to a certain stratigraphic horizon or bed of the Middle Eocene limestones. However, the present authors believe that the "Egyptian Alabaster" is confined to the Eocene carbonate units, particularly the Qarara Formation and is largely controlled (among other factors) by their extent and distribution.

2. The presence of thick shales underlying the concerned carbonate sequence.

3. Structural control though intersecting joints and fractures which increase the permeability and permit continued percolation of surface water as well as the formation of surface and subsurface solution features.

4. Paleoclimatic conditions favouring karstification and pedogenesis under alternating wet (leaching) and dry (deposition) conditions. In this respect, the origin of alabaster by Kamel *et al.* (1990) involves the action of ascending thermal waters related to Tertiary volcanicity for the deposition of the alabaster along fractures, followed by later recrystallization by meteoric water. However, it is to be mentioned that thermal activities affecting similar carbonate rocks did not result in any alabaster or alabaster-liker rocks allover Egypt, especially on the eastern side of the Nile Valley. Also the relatively high concentration in Co, Ni, Cr, Pb. and Zn, which they related to hydrothermal solutions, is most probably the result of enrichment by pedogenetic processes during karstification.

5. Development and fixation of suitable thick subaerial soil associated with vegetation cover.

6. Paleotopographic control, where such deposits accumulated on topographic lows surrounded by highlands during the old (senile) stage of the responsible paleoerosion cycle.

7. Prolonged duration of the meteoric subaerial processes permitting the lowering of the water table to create vadose-phreatic conditions during the major climatic cycle.

8. The degree of crystallinity of the produced intrakarstic deposits depends, to a large extent, on the rate of crystallization and the stability of the geochemical conditions governing the concentration of dissolved carbonates. This, in turn, is related to the cave history and environment.

The presented model for the genesis of the "Egyptian Alabaster" as part of the karst products and associated surficial deposits (terra-rossa and calcrete) is recommended as a field guide for exploration of such economic deposits. Development of the presently known occurrences of "Egyptian Alabaster" along the Nile Valley requires more detailed surface and subsurface examination of the soil profile and associated landforms through the following: a) detection of paleoerosion surfaces; b) tracing the geomorphic features and their genetic models; c) detailed sampling of deep profiles to ensure the presence of subsurface caves and speleothems; and d) the application of analytical techniques for major and trace element contents to get more information about the geochemical evolution during the pedogenetic processes. For evaluating the economic aspects of intrakarstic deposits (Egyptian Alabaster), the use of standards of quality for materials produced for industrial and (or) building purposes, e.g. physical characters, chemical composition, petrophysical parameters, mineral composition.... etc, is recommended.

On reviewing the literature, karst features and karst facies (with or without "Egyptian Alabaster" are recorded in the following localities: 1) At W. El Assiuti and El Issawia (East of Assiut and Sohag, respectively). The Eocene Manfalut Formation (Mansour and Philobbos, 1983) is formed of chertified limestone at the base followed upward by laminated dolomitized lime mudstone interbedded with intraformational conglomerates and nummulitic limestone. The heterogeneity of this sequence is most probably responsible for the development of locally distributed "Egyptian Alabaster" of lower crystallinity and quality than that of W. Sannur area. The exploited red matrix breccia and the associated calcareous deposits of El Issawia (Issawia Formation of Said, 1981), represent terra-rossa deposits superimposed on different karstified Eocene rocks (El Aref, p.c.) that should not be given formational names according to the Code of Stratigraphic Nomenclatare (1961). 2) At El Minia (Tall El Amarna and W. El Shurfa), the Eocene sequence is built up mainly of snow-white, fine grained crystalline limestones of the Samalut Formation that includes solution dolines (Philip, p.c.). Due to the small thickness of the impervious shales underlying the Minia limestones, phreatic conditions could not be maintained for long periods to allow for leaching and redeposi-

tion. Although the resulting karst features at El Minia contain "Egyptian Alabaster", it is of lower quality and local distribution compared to that of W. Sannur. 3) At G. Mokattam, the Mokattam Formation consists of argillaceous limestone with thin shales (Upper Building stone Member), overlain by the sandy argillaceous limestones of Giushi and Maadi formations. This facies type is not suitable for the formation of "Egyptian Alabaster", although huge natural caves and dolines are present. 4). At the northern reaches fo W. Sannur, at the western slopes of the two Galala plateaux, the exposed Middle Eocene carbonates show lithologic homogeneity and karst features suitable for the formation of "Egyptian Alabaster". A thick shale sequence is interbedded with these limestones at G. Tarboul and Kuraimat area (Abdou, 1980). Intrakarstic deposits are recorded in the southern Galala-Zaafarana limestones and north of El Sukhna area. 5) Surficial calcrete and intrakarstic deposits (Egyptian Alabaster) are also recorded in the Cretaceous-Eocene carbonates of Sinai at El Maghara area (Darwish, p.c.); the Miocene sequence of Siwa Oasis (El-Etr, 1977); the upper Cretaceous-Eocene sequence of El Farafra-Bahariya plateau (Abu Khadrah *et al.*, 1987); and the Cretaceous and Eocene rocks of El Bahariya Oasis (El Aref *et al.*, 1987; El Aref and Lotfy, 1985; and El Aref *et al.*, 1990).

The above review shows that the exposed karstified carbonates of the plateaus of the Western Desert, Northern and Southern Galala and north Sinai are promising for further exploration of intrakarstic products (Egyptian Alabaster of economic value.

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أسطح التعرية القديمه ومظاهر الكارست المصاحبة لها والمشتمله على الالباستر المصرى بمنطقة جبل حمره شيبون – جبل سنور، شرق وادى النيل، مصر.

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تهدف هذه الدراسة الى القاء الضوء على التاريخ الجيومورفولوجى للصخور الكربوناتيه لمنطقة حمرة شيبون – جبل سنور، شرق وادى النيل. وقد أمكن الأستدلال على وجود ثلاث أسطح تعريه قديمة ذات ارتفاعات ومظاهر جيومورفولوجية مختلفة نتجت عن تعرض المنطقة لثلاث دورات تعريه متتالية بدأت بعد حركة الرفع الرئيسية فى نهاية عصر الأيوسين وامتدت الى زمن البليوسين. ومن دراسة هذه الأسطح وقطاعات الكارست المصاحبة لها أمكن الأستدلال على الظروف المناخية التى صاحبت كل دورة تعرية وكيفية نشأة الرواسب الكارستيه المصاحبة لها. كذلك أمكن إستنتاج ان العوامل الطوبوغرافيه القديمه، المناخ القديم، السحنه الصخرية والتراكيب وبيئة الكارست السطحية والتحت سطحية وكذلك عمليات مابعد الترسيب هى العوامل الرئيسيه التى تحكمت فى توزيع وتكوين نواتج الكارست المختلفة والتى تشمل صخر الالباستر المصرى.